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## TABLE OF CONTENTS

### Section

### Page

Table of Contents

A.ii

A.1

Introduction

A.1-1

A.2

Input Data

A.2-1

A.3

Size Limitations

A.3-1

A.4

Error Messages

A.4-1

A.5

File Usage

A.5-1

A.6

Overlay

A.6-1

## A.1 INTRODUCTION

This addendum to the BOPACE 3-D (Boeing Plastic Analysis Capability for 3-Dimensional solids using isoparametric finite elements) program document (Ref. 1), describes modifications and additions incorporated into the program version dated September 1, 1975. These include the following major items.

1. Restructuring of the program to allow solution of certain 3000-DOF problems within 64K words of core. (This also increases the allowable equation bandwidth/wavefront for larger core storage allocations).
2. Generalization of the isoparametric element library, which now allows use of an element with any number of total nodes from 8 to 44, with any individual edge having from 2 to 5 nodes arbitrarily spaced along its length.
3. Generalization of the numerical integration scheme to allow an arbitrary number of Gauss points (from 1 to 10) in each coordinate direction, with a default option which automatically selects the number of points in each direction such that the stiffness matrix will be exactly integrated. (This integration is generally exact only if the material properties are uniform within the element and all edges are straight lines).

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Reference 1. BOPACE 3-D, Final Report by The Boeing Company to the NASA Marshall Space Flight Center, Contract NAS8-30615, April 15, 1975. Document D180-18677-1.

4. Provision of user-selected coordinate systems for describing the integration point locations and defining the integration point variables (stresses, strains, etc.).
5. Elimination of the prohibition against displacement constraints between nodes on the same element.
6. Addition of a capability for including elastic anisotropic materials, through user definition of the anisotropic thermal-strain behavior and stress-strain matrix, as functions of temperature.

The following sections discuss the program modifications in more detail. Included are updates to the program input data formats, error messages, file usage, size limitations, and overlay schematic.

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## A.2 INPUT DATA

This section describes the items of BOPACE 3-D input data which have been updated for the current version during incorporation of the new capabilities. In general, these updates are transparent to users of previous data decks, i.e., previous data decks can be run essentially without modification.

C-3. The actual program format for this item has been corrected to agree with the format given in the document. The correct format is (6I5/3F10.0) instead of (6I5,3F10.0). This now requires that input item C-3 use two data cards instead of one (both cards may be blank if default values are used for the various constants in this item).

I-1. Number of anisotropic materials (0-5), number of isotropic materials (0-5), fabrication temperature, and default values for four integration scheme codes.

Format (6X, 2I2, 10X, F10.0, 30X, I4, 3I2)

The number of anisotropic or isotropic materials may be zero, but the total number of materials must be from 1 to 10.

The four integration scheme codes are defined as follows.

1. The first code defines the type of integration scheme, and in the current program version may be given as either 0 (blank) or 1.

Both of these current options result in product Gauss formula integration, with a variable number of points in each of the three parent  $\xi$ ,  $\eta$ ,  $\zeta$  coordinate directions. The 0 specifies an automatic scheme, in which the program automatically selects the number of points in each direction such that the stiffness matrix will be

exactly integrated. (This integration is generally exact only if the material properties are uniform within the element and all edges are straight lines). The 1 specifies user-provided values for number of points in each direction, given as codes 2-4.

2-4. These three codes are given if the first code has a value of 1.

They are the number of points (from 1 to 10) in each of the  $x, y, z$  coordinate directions, respectively. Total number of points may not exceed 600. It should be noted that the stiffness generation time for an element is highly dependent upon the number of integration points, as well as the number of element nodes. For example on the IBM 370, generation time for an 8-node element with 8 integration points is less than 1 second, while generation time for a 44-node element with 125 integration points is almost 1 minute.

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I-2. This item now includes first the isotropic and then the anisotropic material data. (If the number of isotropic or anisotropic materials is 0, the corresponding data is omitted). The isotropic data is given as before. The anisotropic data is given for each consecutive anisotropic material as described in the items below.

a. Thermal strain curves. For each coordinate direction (in integration-point-variable coordinate system) give the following.

Material number (integer from 6 to 10), coordinate component number (1, 2 or 3).

Format (2110)

Thermal strain curve for this coordinate direction. For each curve point give temperature and strain value, with points in order of increasing temperature. User has option of from 1 to 4 points per card.

Format (8F10.0)

Blank card after last point of each curve.

- b. Elasticity matrix definition. (Actual elasticity matrix relating total stress to total elastic strain, is computed at any temperature as an interpolated factor times the input matrix. The factor and input matrix are defined by the following).

Material number (integer from 6 to 10).

Format (I10)

Curve of elastic matrix factors. For each curve point give temperature and factor, with points in order of increasing temperature. User has option of from 1 to 4 points per card.

Format (8F10.0)

Blank card after last point of curve.

Elasticity matrix by rows, with six entries per row. (Order is XX, YY, ZZ, XY, XZ, YZ). Matrix must be symmetric, and defines relationship between stresses and engineering strains.

Format (6F10.0)

- I-7. For each element: element I.D. number, material number (1-5 for isotropic or 6-10 for anisotropic material), the eight corner nodes of the element, the maximum number of intermediate nodes along the edges, I.D. number of coordinate system to describe integration point locations (= 0, 1 or 2), I.D. number of coordinate system to define integration point variables (= 0, 1, 2 or other), and the four integration scheme codes (if these codes are not given they are assigned the default values from input item I-1).

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Format (10I5, 15, 11, 14, 14, 3I2)

If intermediate edge nodes are used, they are input next for each edge in the order shown in the figure (see Ref. 1). The same number of inputs per edge is expected (i.e., the maximum number of nodes per edge as input on the previous card), with zeros used for edges which do not have the maximum number of intermediate nodes. Up to three intermediate nodes per edge may be used, and the total number of intermediate nodes may be up to 36.

I-8. For each degree of freedom with a specified displacement or constraint: give node I.D. number, component number (1, 2 or 3) and code. The code to be given is:

1. For specified displacement, a blank (or may give the negative of the node I.D. number).
2. For dependent constrained DOF, the node I.D. number of the independent DOF in constraint.

User has option of specifying from one to four DOF on each card.

Format (4(3I5,5X))

Blank card after last displacement-constraint DOF.

Note: Specified forces may be denoted by giving the code equal to the node I.D. number. However, this is not necessary because any DOF not specified is automatically assumed to be a specified force.

### A.3 Size Limitations

The following variables are used to specify maximum size limitations in BOPACE 3-D. The values set for these variables are given in Table A.3-1. The first set of values corresponds to the basic 64K program version, while the second set indicates the capabilities which would be obtainable through use of 128K core.

NMAX1 - NMAX14	= values as defined in Ref. 1.
MAXNPE	= maximum number of nodes per element
MAXINT	= maximum number of integration points per element
B	= maximum wavefront (in nodes)

Table A.3-1: MAXIMUM PROGRAM SIZE LIMITATIONS

<u>VARIABLE</u>	<u>64 K CORE</u>	<u>128 K CORE</u>
Problem DOF	3000	3000
NMAX1	5	5
NMAX2	1000	1000
NMAX3	500	500
NMAX4	5000	5000
NMAX5	2000	2000
NMAX6	20	20
NMAX7	6	6
NMAX8A	30	30
NMAX8B	20	20
NMAX8C	30	30
NMAX9	10	10
NMAX10	6	6
NMAX11	10	10
NMAX12	1000	1000
NMAX13	2	2
NMAX14	60	60
MAXNPE	44	44
MAXINT	600	600
B*	61	99

\* Based on MAIN program STOR array dimension of 38,000 for 64 K, and 102,000 for 128 K. Larger STOR array allows larger B.

#### A.4 ERROR MESSAGES

The following error message stop code definitions have been added, deleted or modified.

- 351 Wrong material number input on an anisotropic thermal strain card.
- 352 Number of points input for an anisotropic thermal strain curve exceeds maximum.
- 355 No points input for an anisotropic thermal strain curve.
- 481 Wrong material number input on an anisotropic elastic matrix factor card.
- 482 Number of points input for an anisotropic elastic matrix factor curve exceeds maximum.
- 385 No points input for an anisotropic elastic matrix factor curve.
- 718 I.D. of an integration point location coordinate system not equal to 0, 1 or 2.
- 719 I.D. of an integration point displacement coordinate system is less than zero or greater than the maximum.
- 721 The number of interior edge nodes on a side of the next element exceeds 3.
- 720 The total number of integration points of an element is zero, negative, or exceeds the maximum.
- 805 (Deleted)

## A.5 FILE USAGE

The following files have been added to BOPACE.

<u>Unit Number</u>	<u>Description</u>	<u>Defined by</u>
INODAL (=21)	Nodal data	BLKDTA
ISCR1 (=22)	Contains temporary element data when BIGSC is called. Otherwise contains the load array PREF.	BLKDTA
ISCR2 (=23)	Contains data that is to be added to the checkpoint tape	BLKDTA

## A.6 OVERLAY

The overlay of BOPACE was designed to minimize loading of segments and to maximize the size of the MAIN program STOR array (common JLB) for a given core size. A schematic of the overlay is shown in Figure A.6-1.

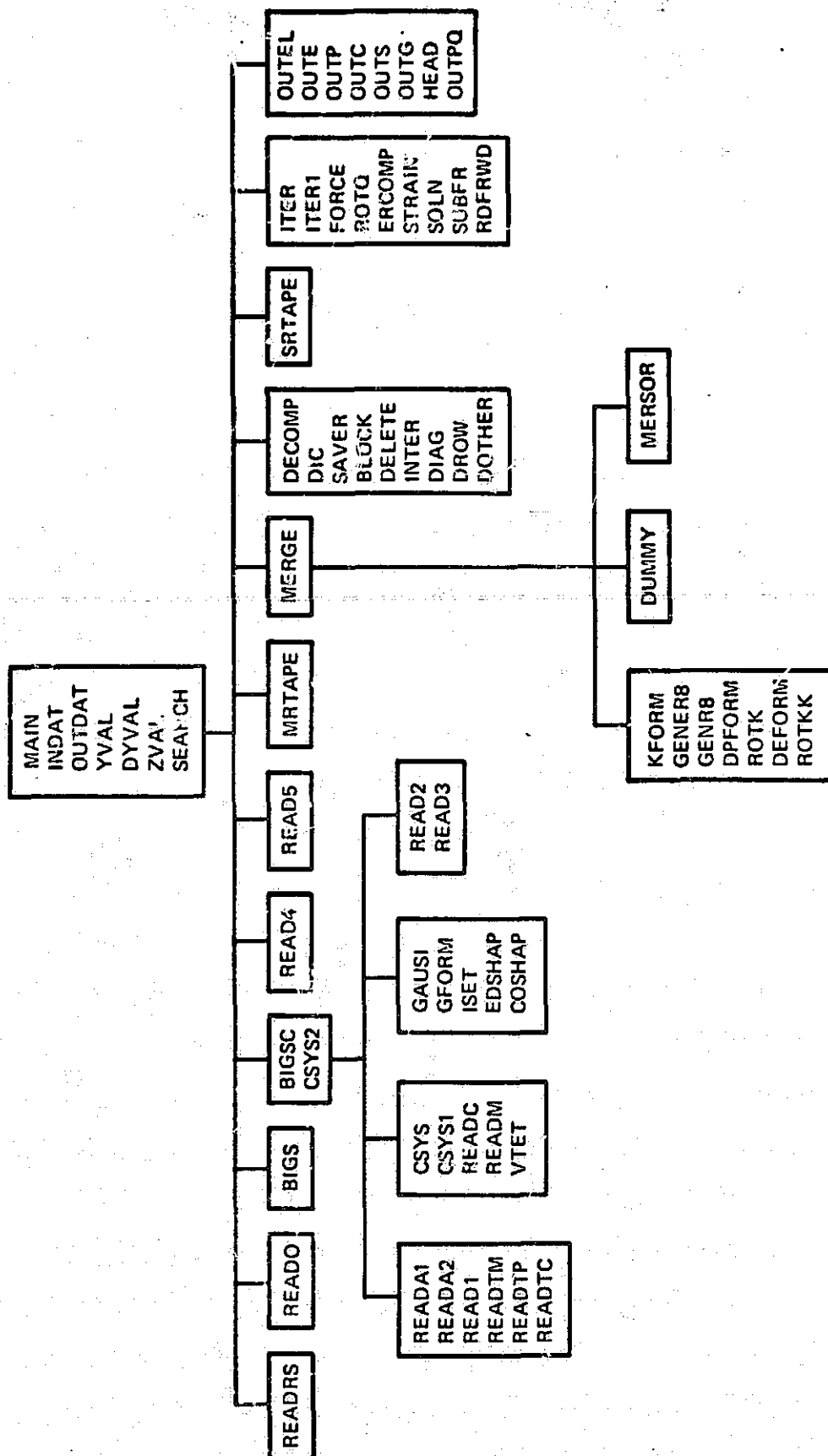


Figure A.6-1. Overlay Schematic